**Study on the impact assessment for a new Directive mainstreaming deployment of renewable energy and ensuring that the EU meets its 2030 renewable energy target**

**Task 3.1: Historical assessment of progress made since 2005 in integration of renewable electricity in Europe**

**and first-tier indicators for flexibility**

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Summary

An increasing share of RES-E entails a number of system challenges: The energy system needs to adapt in order to accommodate large shares of RES-E. One of these challenges is the increasing demand for flexibility. Due to the fact that many renewables are both variable and uncertain, flexibility needs to be provided to deal with these characteristics.

This report proposes a set of indicators that can be used to measure that flexibility and looks at the development of flexibility in the European Union in the last decade.

The indicators provide the basis for describing the overall flexibility that is available and how this can match the flexibility demand in a given system. These indicators for flexibility demand and supply can be considered as a first-tier approach that can provide a rough overview for a given system, without a detailed modelling exercise that can provide a more detailed picture.

Within this report we develop three different indicators:

* Indicators that show the demand for flexibility
* Indicators that focus on the supply of flexibility
* Indicators that represent the gap between the previous two

Overall, our research that is based on these indicators show that the flexibility in EU electricity systems has increased over recent years.

The analysis of the case studies (see section 2.3) shows different developments for individual Member States. The development of variable and flexible generation differs strongly between Member States. In a EU context, these differences can balance each other out, as some Member States e.g. provide more flexibility than others.

# Introduction

An increasing share of RES-E entails a number of system challenges: The energy system needs to adapt in order to accommodate large shares of RES. One of these challenges is the increasing demand for flexibility to match supply and demand for electricity. Due to the fact that many renewables are both variable and uncertain, flexibility needs to be provided to deal with these characteristics.

In order to assess in more detail what kind of flexibility is needed and when it is needed, we propose a differentiated view on flexibility that distinguishes between:

* different system contexts,
* different flexibility functions,
* different flexibility options

In terms of system contexts, the demand for additional flexibility depends on

* the share of RES-E (Kondziella & Bruckner 2016). Many studies show that the demand for additional flexibility increases substantially not before RES-E have reached a share above 50% (Bauknecht 2014; Bauknecht et al. 2014; DIW 2013; VDE 2012);
* grid bottlenecks. With grid constraints flexibility may be needed even at lower RES-E shares;
* the kind of flexibility that is already available in the system and that can be exploited, before new flexibility options and new technologies are set up, i.e. mainly conventional plants and pumped hydro storage.

In terms of flexibility functions, it is important to note that the different flexibility options can serve different purposes.

* Some flexibility options can be used to cover a capacity shortfall.
* Some flexibility options can be used to accommodate surplus RES-E generation.
* Some flexibility options can be used to accommodate surplus RES-E generation and use it to replace conventional generation or capacity.
* Moreover, new flexibility options can be used to replace existing flexibility in the system.

The evaluation of a system’s flexibility can be conducted by different means. IRENA (2017) provides an overview of different models that can be applied. One approach is an evaluation of consumption and generation patterns. Gradients of load curves and ramping needs that result from this are compared with a system’s generation which has to satisfy these needs. Models that are applied among others to evaluate a system’s flexibility performance are InFLEXion, FlexAssessment and FAST2.

In this report we present indicators for the demand, supply and the gap in flexibility (section 2). The goal is to present simple and easy to use “first-tier” indicators that do not require extensive modelling exercises. Based on this, we look at specific Member States in order to illustrate the use of the indicators (section 3). Moreover, we analyse the historic development of the supply of flexibility (section 4).

# Indicators for flexibility

## System flexibility: A first-tier approach

This report focusses on indicators for system flexibility that do not require extensive modelling exercises. Its aim is to propose easy-to-use first-tier indicators for flexibility that can be applied on a Member State level.

Ideally, flexibility within the European Union and within Member States should be evaluated using a model-based approach (see text box below: “Second-tier approach: Detailed system modelling”), since this would provide the most comprehensive understanding of the flexibility that is in place and of any requirements to develop further flexibility. As such approach is not always possible for all Member States, this simplified approach is proposed.

This report distinguishes among three main types of indicators for a system’s flexibility:

* Indicators that show the demand for flexibility
* Indicators that focus on the supply of flexibility
* Indicators that represent the gap between the previous two

While the gap indicators directly provide a proxy that shows whether or not there is sufficient flexibility in a system, the flexibility gap can also be established by comparing the demand and supply indicators.

**Second-tier approach: Detailed system modelling**

The evaluation of flexibility needs in a system can be carried out by a detailed analysis that is based on computational models or by a more basic approach which this report focusses on. A model-based analysis has been carried out by Artelys within this project, see the report: “Design of flexibility portfolios at Member State level to facilitate a cost-efficient integration of high shares of renewables”.

In-depth modelling exercises can provide a more detailed analysis of an energy systems flexibility demand that also takes into account load and generation profile as well as the profile of flexibility supply, as well the temporal dynamic between them. By analysing the structure of renewable generation and the flexibility that can be provided by available flexibility options the amount of necessary flexibility can be concluded. Assessments can be carried out for different scenarios that describe the generation and consumption patterns in the future.

The deduction of the residual load curve is realised by subtracting the initial load curve from non-flexible renewable generation. By modelling the dispatch of flexible generation and consumption the times of excess generation and shortages can be compensated through flexibility options. Load that cannot be covered by this shift of renewable generation or excess renewable generation that needs to be curtailed are indicators for a system’s need for flexibility.

Flexibility need has different characteristics which can be compared to the characteristics that describe electricity storages:

* Positive capacity [MW]
* Negative capacity [MW]
* Storage capacitiy [MWh]

The following diagram shows how those three main indicator types relate to each other and gives an overview of specific indicators that feed into these main indicators and that will be discussed in the following sections in more detail.

|  |
| --- |
| Figure 2‑1: Indicators for flexibility |
| Source: Authors‘ own depiction |

Based on these main indicator types we propose the following structure for an analysis on a MS-level as well as for comparing Member States. This approach aims at evaluating the supply of flexibility in a system’s context and combines three perspectives: comparing supply and demand in a simple way, relating the supply of flexibility to the system size, and assessing the gap indicator. This approach is applied in section 3 for Germany, UK and Denmark.

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| Table 2‑1: First-tier indicators: Methodology for analysing the flexibility of a system |

|  |  |  |
| --- | --- | --- |
|  | Possible illustration based on indicators | Interpretation of indicators |
| Variable versus flexible generation/flexible capacity |  | This comparison of the variable and the flexible generation in one MS can express:   * the absolute level of variable and flexible generation capacity * How the gap between the variable and flexible capacity develops over time   MS can be compared to a certain extent to one another by comparing the gap between variable and flexible generation. |
| Comparison of flexible generation/flexible capacity in relation to peak load between MS |  | This indicator focusses on the comparison between MS:   * The relative value shows how much of the peak load can be supplied by flexible generation or other flexible options. * However, the percentage does not imply that 100% of the peak load has to be covered by those options as variable RES-E plants also supply a secured generation of about 6%[[1]](#footnote-2). |
| Flexibility Gap (that can be observed in the system) |  | The hours per year with negative prices at the spot market as well as the absolute value of curtailment per year give a good impression of the:   * flexibility of the system overall (indicator: negative spot prices) * status of the grid in order to integrate RES‑E generation * MS can be compared to one another (however the absolute value of curtailment has to be interpreted in relation to the overall RES-E generation) |

|  |
| --- |
| Source: Authors‘ own depiction |

More detailed description of input into first-tier indicators

This section provides more detailed information on flexibility demand, supply and gap. In the following section 2.2.1 a more detailed list of indicators for each of three indicator types is presented. Sections 2.2.2 to 2.2.4 present some more background for these three indicators types.

### Overview of indicators

The previous section distinguishes between

* Indicators that show the demand for flexibility
* Indicators that focus on the supply of flexibility
* Indicators that represent the gap between the previous two

As indicated in Figure 2‑1, there can be a range of different more detailed indicators that feed into the overall demand and especially the overall supply of flexibility. For example, flexibility supply and the flexible capacity that is available can be based on storage plants, flexible power plants or demand-side management etc. There are also different indicators for the flexibility gap.

Moreover, while the approach presented in section 2.1 and especially the indicators for demand and supply focus on available capacities, there are also more detailed indicators that can show

1. the flexibility challenge that results from a certain variable RES-E capacity
2. how flexible a system is and how good it is at integrating RES-E, e.g. in terms of market design that helps to use the supply of flexibility in an efficient way.

The following table presents an overview of this more detailed list of indicators for flexibility demand, supply and gap (for the gap the two indicators in the list have been used before in section 2.1.). For this more detailed list it is not straightforward to combine the different indicators into an overall picture of the flexibility situation in a given system, especially for indicators that cannot be measured in MW. Nevertheless, these more detailed indicators and their development over time can help compare systems and assess how their capacity to integrate RES-E develops over time. For the supply indicators this is done in section 4.

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| --- |
| Table 2‑2: Overview of suggested first-tier indicators for flexibility |
| |  |  |  | | --- | --- | --- | | Flexibility supply indicators | | | | **Indicator** | **Description** | **Interpretation** | | **Flexible power plant fleet capacity** | Power plants with high load gradients are able to adapt their generation quickly to variable RES-E generation (see section 4.1). | The share of flexible power plant capacity of the total power plant capacity **[%]** can act as an indicator. High shares indicate that fluctuations of residual load can be balanced out. Small shares indicate a lack of flexibility. | | **Storage capacity** | Storage plants can store electricity over time and can thus provide positive and negative flexibility to balance demand and supply both in times of over- and undersupply (see section 4.2). | Storage becomes particularly relevant when there are times of excess RES-E generation that could not be used without storage and where flexible power plants do not help. However, this becomes relevant only at RES-E shares well above what can be observed in most Member States for the time being. Long-term storage options such as Power-to-Gas are typically required only at RES-E shares above 80 %.  A possible indicator unit could be the share of storage capacity of a system’s maximum load. | | **Demand side management capacity** | Flexible demand can adapt to RES-E generation by shedding or shifting loads (see section 4.3). | The DSM capacity as a share of the maximum load or the maximum residual load **[%]** can provide information on the contribution that DSM can have to balance demand and supply. As opposed to other options like storage plants, the flexible capacity DSM can provide is time-dependent as a certain demand profile has to be met, and this may not correlate with the profile of flexibility demand. |  |  |  |  | | --- | --- | --- | | Indicator | Description | Interpretation | | **Intraday market volume** | A liquid intraday market provides flexibility through short-term coordination of supply and demand, which is particularly important with a high share of variable RES-E generation (see section 4.5.1). | An increasing market volume **[TWh]** can provide information on the market liquidity and on whether flexibility can be provided by the market in an efficient way. | | **Market design I – Gate closure time** | Shorter gate closure times increase the RES-E prediction accuracy, and thus the efficiency of flexibility planning (see section 4.5.2). | Short gate closure times **[min]** of around 15 minutes are currently common and can serve as a reference value. | | **Market design II – Product definition** | Requirements for contributions to the balancing market can vary in size (MWh) as well as time resolution. Small MWh sizes and shorter time periods for which an offer needs to be made can lead to the participation of flexible capacities from smaller market participants (see section 4.5.2). | Product sizes exclude small consumers. With increasing flexibility demand and new and innovative flexibility products market rules need to be reviewed. Yet it has to be taken into account that a large number of participants and small product sizes increase the coordination effort of a market. | | **Grid integration between Member States** | By strengthening grid connection between EU Member States additional flexibility can be provided through electricity exchange between states. (see section 4.5.3.1) | At lower RES-E levels, flexibility options such as flexible power plants can be jointly used by Member States. At higher RES-levels, different RES-E generation profiles can balance each other out.  A benchmark for the integration of European grids could be the European target value of interconnection capacity **[GW]** of 15% of generation capacity in 2030 for each Member State. However, this indicator needs to take into account that with RES-E the generation capacity typically increases.  A key problem is that grid development can face significant acceptance problems.  . | | **Integration of markets** | Similar to the grid integration between Member States, the integration of markets leads to an optimization of dispatch over larger areas, which reduces the overall need for flexible capacity to balance RES-E variations and can facilitate its efficient operation. (see section 4.5.3.2) | Market integration can be assessed either on the basis of market rules, or based on the difference in spot market electricity prices. Similar prices are a sign of a high degree of market integration. Market integration depends on grid integration. | | **Flexibility demand indicators** | | | | **Indicator** | **Description** | **Interpretation** | | **Share of variable RES-E** | Variable RES-E cause deviations of generation from inflexible consumption. The RES-Share can act as a proxy for flexibility needed in the system. | With increasing shares of RES-E **[% of overall generation]** the need for flexibility increases. | | **Variability of PV and wind generation** | The generation of RES-E may be more or less variable depending on geographical characteristics or the technologies that are deployed. For example, weak wind turbines can contribute to a less variable generation profile. | An interpretation of load gradients **[%/min]** of different Member States’ generation profiles can yield information on the generation’s effect on flexibility needs. | | **RES-E forecast accuracy** | Besides the intermittent pattern of RES-E generation, short-term deviations from forecasted RES-E generation can increase the demand for flexibility. The forecast accuracy helps to reduce this problem. | The ex-post comparison between actual generation and the forecast can yield information about the forecast accuracy of a system.  Improving the forecast accuracy can enable a more efficient dispatch of flexible capacity and can reduce the volume of flexible capacity that is needed. | | **Seasonal differences in PV and wind generation** | Especially between summer and winter large differences between PV and wind generation patterns can be observed. The solar production is higher during summertime, while wind generation tends to have an opposite behaviour. In combination with the demand profile, this influences the demand for flexibility on an annual level. |  | | **Load temperature sensitivity** | This indicator looks at the demand of electricity and describes the effect of temperature changes on electricity demand.  This also influences the demand for flexibility on an annual level. | The change of electricity consumption in dependence of a temperature change **[MW/°C]** can yield information demand for flexibility that results from temperature changes.  This effect can be very different from one Member State to the other depending on the portfolio of heating technologies. | | **Ramping rate of residual load[[2]](#footnote-3)** | The average hourly ramping rate per hour of the day can provide an assessment of the additional flexibility that is required from the power system when the deployment of RES-e technologies increases. | In particular, the following indicators can be useful: maximum ramping rate (in **GW/h**), histograms of ramping rates (to estimate the number of hours during which a given ramping rate is required) | | **Flexibility gap indicators** | | | | **Indicator** | **Description** | **Interpretation** | | **Negative spot market prices** | Negative prices on the spot markets are a sign of excess generation that can result from RES-E generation. | RES-E generation above demand in certain hours will only occur at RES-E shares above what is currently available in most Member States. Another source of excess generation can be conventional power plants that are inflexible either for technical or economic reasons, or because they need to cover a heat demand in the case of CHP plants.  The number of hours **[h]** with negative spot market prices can indicate the gap between flexibility demand and supply and how this develops. A high number of negative spot market prices show a large gap. | | **RES-E curtailment** | A lack of grid capacity can lead to curtailment of renewable generation. If grid development cannot keep up with RES-E expansion this can lead to increasing curtailment rates. | An evaluation of curtailment can indicate to what extent the grid is capable of integrating RES-E and how this develops over time. A high amount of curtailment **[MWh]** shows a large integration gap.  NB: Some countries prefer not to integrate each unit of renewable generation as this would lead to high investments in grid capacity. During peak generation it can be economically efficient to curtail generation rather than further investing in the grid. At the same time, with further RES-E development ahead, further grid investments are needed anyway, so curtailment cannot replace but only postpone grid investments. |   Source: Authors‘ own depiction. |

### Demand for flexibility

The demand for flexibility has historically been driven by the **variable demand for electricity** over time. The variability of demand will also be in future one major indicator for flexibility demand. Current trends in line with the energy systems transition like increasing shares of heat pumps as well as electric vehicles might even increase the variability of electricity demand (e.g. Peak-loads and load gradients).

With **increasing shares of RES-E** plants, the residual load (load minus RES-E generation) has to be supplied by the electricity system. Hence the gaps between peak and minimum load become larger and ramps in-between those become steeper.

Figure 2‑2 shows the overall development of renewable capacities in the European Union since the year 2000 and illustrates the need to adapt the system to this development.

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| --- |
| Figure 2‑2: Development of European \*) installed wind and solar capacity from 2009 to 2014 |
|  |
| Source: Authors‘ own depiction based on (Platts 2015; statista 2016)  \*) Including non-EU Member States |

While this figure shows the overall development, the assessment of progress made should also bear in mind that certain measures only gain importance and corresponding business models only become viable once a certain RES-E share has been reached. While efficient intraday-markets should be developed even at low RES-E shares, not the least because they are generally important in competitive electricity markets, the deployment of demand response especially for smaller consumers becomes attractive only at a RES-E share that has not been reached yet in many Member States. Therefore, a lack of such a deployment cannot necessarily be interpreted as a lack of RES-E integration at the current RES-E deployment stage. Nevertheless, it is important to proactively develop such options so that they are available when they become necessary.

It is important to stress that most EU Member States have RES-E shares of around 30% (see Figure 2‑3).

|  |
| --- |
| Figure 2‑3: RES-E shares 2014 of the European Member States |
|  |
| Source: (Eurostat 2015) |

For RES-E shares below ca. 80 %, there is typically mainly demand for short-term flexibility, so that in principle all options (demand side management, batteries, PHS, etc.) can be used to cover that demand. Options like power-to-gas are relatively expensive, but can become a relevant option when there are long periods of RES-E surplus and deficit that cannot be covered by other flexibility options. However, these long deficit and surplus periods will only be seen with RES-E shares above 80 %.

Yet, the demand for flexibility cannot be associated with the increasing shares of all RES-E technologies alike. While for example hydro storage plants provide great flexibility themselves, especially photovoltaics and wind generation are both variable as well as hard to forecast. Therefore those are the technologies that have to be focussed on when analysing the increasing demand for flexibility (IEA 2011).

Suggested indicators for flexibility demand are

* **Share of variable RES-E [%]:** As variable RES-E photovoltaics and wind should be in focus. The share should be calculated by using the installed capacity of PV and wind and put into relation to a systems peak demand.

### Supply of flexibility

Different options can provide flexibility in a system. Next to technological options such as flexible power plants and storages also non-technological flexibility options may contribute to a systems ability to integrate renewable energies, such as the electricity market design.

**Flexibility of power plant fleet**

Traditionally **conventional power plants** provide flexibility in the electricity system. Their ability to ramp up and down according to the demand or renewable generation profile supports a system’s stability. A fitting indicator that can give an impression of the flexibility provided by a system’s power plant fleet can be the share of flexible power plants of the overall generation capacity. Traditionally gas power plants are characterised by high load gradients and therefore flexibility. Other technologies may fulfill the same functions, for a detailed description see chapter 4.1.

**Storages** can compensate the inflexibility of other electricity generators or demand. They can shift e.g. renewable generation from times of excess generation towards times of generation shortages. Pumped hydro storages are an established technology and are an example for this functionality. Recently other technologies such as battery storages are used more frequently. As flexible power plants the storages enable a system to integrate larger shares of renewable generation. An indicator for the contribution of flexibility to the system can therefore be the storage capacity as a share of maximum load. Also the volume of storage in comparison to excess demand can give an impression of the ability to supply times of excess demand and can act as an indicator.

Another rather innovative flexibility option is the flexibility of demand **(demand side management)**. Flexible demand either shifts consumption over time or sheds consumption and thereby adapts to renewable generation. As of today rather small capacities are availableon the market. Similar to the evaluation of storage capacity the demand side management capacity as a share of the maximum load of a system can act as an indicator for flexibility provided this way.

The electricity grid and especially the **interconnection capacities** provide the option to balance loads and generation over large areas and thereby increase overall flexibility. On a European level flexibility is especially provided through interconnection between Member States.

In terms non-technological flexibility the design of electricity markets can also act as an indicator for the flexibility of a system. **Gate closure time**sthat define the time between the end of electricity trading in a market (gate closure) and the time of its delivery can have an impact on the flexibility that is needed in a system and on how efficiently flexibility can be supplied. With increasing gate closure time the forecast accuracy decreases. This leads to an overestimation of flexibility needs and the corresponding capacity that needs to be on “stand-by”. Systems with short gate closure times therefore reduce their flexibility needs.

The possibilities for flexibility options to participate in a market are also defined by **market rules**. Although certain threshholds for capacity and duration are necessary to reduce a system’s complexity, these rules can also exclude especially smaller flexibility options from market participation and thus from providing their flexibility to the system in an efficient way.

A **liquid intraday market** provides short-term, market-based flexibility that is necessary to deal with the short-term variations of RES-E generation. The availability of such a market and the amount of electricity traded in it can act as an indicator for the ability of a system to integrate RES-E in a flexible way.

### Flexibility gap

The current gap between the supply and the demand of flexibility within an electricity system can be detected by two indicators that are reasonably easy to assemble:

* Negative prices on the sport markets
* Curtailment of RES-E

However, these two indicators address different causes for inflexibility. While curtailment of RES-E focusses on grid bottlenecks, negative prices on the spot markets indicate a much wider set of origins for inflexibility.

**Negative prices on the spot markets** are caused by excess generation of electricity in a system. Excess electricity follows from large amounts of RES-E which can hardly adapt to the current state of the electricity market in combination with inflexibility of conventional power plants. Especially base load power plants with low load gradients are not able to reduce their generation in times of decreasing electricity prices and high RES-E generation. This reinforces the downward trend of market prices. In Germany 64 hours of negative prices occurred in 2013, which shows a lack of flexibility of base load power plants (Agora Energiewende 2014).

**Missing grid capacity** can lead to curtailment of renewable generation. Depending on the speed of renewable expansion it can be difficult to increase grid capacity in time to sufficient levels, which can lead to increasing curtailment rates.

Figure 2‑4 shows the development of curtailment of wind generation as a share of total wind generation since 2009 in Germany, Ireland and Italy. The figure shows a decrease in the curtailment rate of Italy and an increase in curtailment rates of Germany and Ireland. Wind generation increased steadily over the years in all three Member States as depicted by the bars.

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| --- |
| Figure 2‑4: Curtailment of wind generation [lines] and wind generation as a share of final consumption [bars] since 2009. |
|  |
| Source: Authors‘ own depiction based on (Bundesnetzagentur 2015, 2016; EirGrid et al. 2014, 2015; European Commission 2015b; Yasuda et al. 2015) |

With an increase of wind generation in Germany and Ireland the share of curtailed generation from this energy source increased as well. Although wind generation doubled in Ireland and grew by almost 40% in Germany the curtailment quintupled in Ireland and decupled in Germany. This shows that curtailment is growing stronger than wind generation and increasing amounts of flexibility become necessary.

An important measure to tackle this problem is to increase a system’s flexibility by providing sufficient grid capacities through grid expansion. This ensures the transport from generation to consumption and curtailment of renewable can be avoided.

## A methodology example from the literature

At the end of this section, we would like to briefly present another first-tier approach from the literature. Yasuda et al. (2013) applied a flexibility spider chart to assess the flexibility configurations of different European Member States. An overview of four charts is given in Figure 2‑5 for the states Germany, Denmark, Portugal and Ireland. Flexibility parameters that are evaluated in this approach are the capacity penetration of the following flexibility options:

* Interconnection
* Combined Heat and Power (CHP)
* Combined Cycle Gas Turbine (CCGT)
* Pumped Hydro Storages (PHS)
* Hydro power plants

In practice it can be observed that different Member States approach the flexibility challenge in different ways. The viability of a strategy depends on a number of different factors, such as the location of a state within the European energy system, its energy resources, market design and framework conditions and its energy policy.

These parameters depict the most important flexibility options as of today. In the near future additional flexibility options will become more important such as demand side management. These options could be included in the chart. Especially for the development of future flexibility configurations an expanded chart could be useful.

Which flexibility configuration a state can put into place depends on the characteristics mentioned earlier. The installation of PHS and hydro power plants depends on a state’s topography as these technologies depend on the presence of altitude differences and rivers. Not all states can provide these properties. As can be seen in Figure 2‑5 Portugal is realizing flexibilities to a large extent in the form of hydro power plants and PHSs. The interconnection flexibility on the other hand is poorly developed as in the case of Ireland. In contrast to this Denmark and Germany show a large share of flexibility in the form of interconnections. This depends on the location of the states as both states are situated in a region, which provides the possibility to establish interconnections with other states.

In states that lack the possibility to provide sufficient flexibility by establishing interconnections gas power plants can provide flexibility. Figure 2‑5 shows that this is the case for Ireland and Portugal. Denmark on the other hand complements its interconnection flexibility by the use of flexible CHP plants, which operate with higher efficiencies in comparison to gas power plants as they provide heat in addition to electricity. For states such as Portugal this is not an optimal solution as due to climatic reasons the demand for heat is not as well developed.

Another factor that can influence the type of flexibility that is applied in a system is the market design and participatory conditions for potential flexibility providers such as flexible consumers. Currently this flexibility option plays a minor role in the overall flexibility configuration. In what way DSM will develop in the future depends to a large extent on if participation in electricity markets is possible for consumers.

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| Figure 2‑5: Flexibility charts of different Member States in 2011 |
|  |
| Source: (Yasuda et al. 2013) |

From Figure 2‑5 follows that there are different ways to address the flexibility challenge. Although similar approaches could be applied in a country, not all approaches are optimal in each country. Different characteristics influence the possibilities a country may have to address the need for flexibility and the viability of these options.

# Case study: Flexibility indicators for Germany, UK and Denmark

In the following we exemplify the use of the suggested indicators for Germany, UK and Denmark. The data obtained is based on Eurostat as well as the Scenario Outlook & Adequacy Forecast by ENTSO-E. The data focusses on the years 2011 to 2015. However, not all necessary data was available for all indicators or for all years.

## Variable versus flexible generation

The following diagram shows the variable as well as the flexible generation in Germany, Denmark and Great Britain from 2011 to 2015. Flexible generation includes gas fueled power plants, pumped hydro storages and oil fueled power plants. Also import capacities (electricity grid) have been included. Other storage options like demand side management as well as batteries are not specified in the source and therefore couldn’t be included in the diagram. However, those options are not expected to have major impact on the overall result.

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| Figure 3‑1: Development of variable and flexible generation in Germany, Denmark and Great Britain from 2011 to 2015 |
|  |
| Source: Authors‘ own depiction based on (ENTSO-E 2011, 2012, 2013, 2014, 2015a) |

The diagram shows the following effects:

* The flexible capacity has not increased significantly in the three MS analyzed.
* The flexible capacity has even decreased in GB over the period of time in question.
* The variable generation has increased significantly Germany.
* The gap between variable and flexible generation has increased in Germany and UK due to either decreasing flexible capacities or increasing variable capacities.
* Danish variable and flexible capacities stay on a constant level over the period of time in question.

## Comparison of supply of flexibility between MS

The following Figure 3‑1 shows the development of the share of flexible generation in relation to peak demand in Germany, Denmark and Great Britain from 2011 to 2015. Flexible generation includes: gas fueled power plants, oil fueled power plants as well as interconnection capacities. As it is assumed that at times with peak load, the neighboring countries also have high loads, the shares are also displayed without taking the interconnection capacities into account.

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| Figure 3‑2: Development of the share of flexible generation in relation to peak demand in Germany, Denmark and Great Britain from 2011 to 2015 |
|  |
| Source: Authors‘ own depiction based on (ENTSO-E 2011, 2012, 2013, 2014, 2015a) |

Figure 3‑1 displays:

* Over time the relative flexibility does not change substantially.
* Looking at the flexibility without taking interconnections into account, the three case study member states show shares of flexible generation from 40 to 70%.
* Denmark can offer great flexibility. However, this flexibility is significantly based on import capacities. It is to be questioned if import of electricity is an option at times of maximum load.
* Germany seems to have the least available flexibility compared to the other two member states.

Flexibility Gap

The following two diagrams show the flexibility gap using the hours per year of negative prices on the spot market and the amount of curtailed generation due to grid constraints as indicators.

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| Figure 3‑3: Hours per year of negative prices on the spot market for the market regions of Germany/Austria/Luxemburg, Denmark 1&2 and Great Britain |
|  |
| Source: Authors‘ own depiction based on market data from entso-e as well as (Energy Brainpool 2017) |

The following conclusions can be drawn from Figure 3‑3:

* In 2015 negative prices could be found in Germany and Denmark. In Great Britain negative prices did not occur in 2015.
* The hours with negative prices have increased in Germany over time from around 60 to almost 100 hours per year. This matches the findings of the previous indicators that show increasing penetration of variable generation alongside relatively stable levels of flexible generation in Germany.
* Denmark is split up into two bidding zones (DK1 and DK2), both of these zones show negative prices in 40-60 hours per year. As Denmark faces 5 GW of variable generation capacity, high variable generation in times of low demand could be an explanation for these negative prices.

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| Figure 3‑4: Amount of curtailed generation due to grid constraints in Germany and Great Britain |
|  |
| Source: Authors‘ own depiction based on (BNetzA 2017; WindEurope 2016) |

The following can be seen from Figure 3‑4:

* Curtailment increases in both member states.
* The levels of curtailment are still relatively low.

# Historic development of the supply of flexibility and RES-E integration

The supply of flexibility and the resulting integration of RES-E can be measured by a range of different indicators in different areas. In the following chapter the historical development of different flexibility indicators for the supply of flexibility is examined.

* Deployment of flexibility options (see sections 4.1, 4.2 and 4.3). Another key requirement for RES-E integration is the deployment of flexibility options. These can in principle be used both on the network and the market side. This includes demand-response flexibility measures, which we also consider to be one of the most attractive flexibility options in the short- to medium-term. It will be important to differentiate between domestic and commercial/industrial consumers. Another attractive short-term flexibility option can be heat storage and power-to-heat. It is also important to look at the flexibility of conventional power plants.
* Measures to integrate RES-E into the network. This has a national (for the development of smart grids see section 4.4) as well as a European dimension (see section 4.5.3.1).
* Measures to integrate RES-E into the markets (see section 4.5). One important aspect of this debate is the development of RES-E support schemes towards a stronger market integration of RES-E. This dimension will not be covered here. A second important aspect, which is covered, is the development of markets that are capable of dealing with the variable and uncertain nature of the majority of RES-E. This includes the development of intra-day markets to deal with the uncertainty of RES-E generation, as well as a market-based approach towards real-time ancillary and system services. Besides providing additional flexibility options, it is also important to reduce the flexibility demand in the first place. This can be addressed for example by the market design as discussed in section 4.4.

## Dispatchable capacity

With increasing electricity generation from intermittent RES-E sources the conventional power plant fleet can provide a relevant source of flexibility, but needs to adapt to these changes. Besides other forms of flexibility, controllable generation capacity can play an important role in matching consumption and the variable generation of renewable power plants.

However, some power plants are more suitable than others to ramp up and down, and thus to provide flexibility. In general there are three options for the conventional power plant fleet to adapt to the rising shares of RES-E:

1. **Adaption of plant operation**. Former base load plants will for example ramp up and down more frequently within their technological limitations.
2. **Technological upgrade (retrofit)** of conventional power plants in order to make plants more flexible.
3. **Substitution of inflexible power plants** with power plants that are based on other technologies or fuels that make a more flexible operation possible.

Based on those three options we examine the main research question *“How did the flexibility provided by the conventional power plant fleet evolve throughout the last decade”* by analysing the following issues:

* How did the generation patterns of the power plant fleet change due to increasing need for flexibility? Is this due to technological updates of the plants in question?
* Which power plants technologies are most suitable to ramp up and down?
* How did the shares of certain technologies within the European power plant fleet evolve throughout the last decade and, as a result, how has the flexibility increased?

**How did the generation patterns of the power plant fleet change due to increasing need of flexibility?** **Is this due to technological updates of the plants in question?**

Looking at the full load hours of conventional power plants (especially coal and nuclear plants) in Germany, no evidence could be found that those power plants are operated in a more flexible manner today compared to ten years ago[[3]](#footnote-4). In addition, there is no detailed data available that would differentiate between plants that have undergone retro-fit activities and those that have not. However, the following diagram shows the operation pattern of lignite and hard coal plants in Germany for the year 2015. The diagram shows that those plants clearly react to seasonal, weekly as well as daily system needs based on the market price. Hard coal plants show a higher flexibility compared to lignite plants. Due to the lack of data, those operation patterns cannot be compared with patterns from ten years ago but it shows that today those plants are obviously operated with quite a high flexibility.

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| Figure 4‑1: Operation of lignite and hard coal fired plants in the year 2015 in Germany (hourly data) |
| Source: [www.eex-transparency.com](http://www.eex-transparency.com) | Please note: Missing Data for the end of October and end of December 2015 |

Operating existing power plants that are constructed as base load plants in a flexible manner can increase the wear and tear of those power plants. Stakeholders at a workshop organized by the BMWi in Germany BMWI & dena (2013) pointed out the following effects:

* Increased down times due to more frequent up- und down-ramping
* Fatigue of materials due to more flexible operation
* Reduced efficiency of the power plant in question as plants are designed to generate the optimal efficiency close to full load

However, with so called retro-fit measures, existing power plants can be updated in order to provide increased flexibility without risking higher wear and tear (Lefton & Besuner 2006).

BMWI & dena (2013) pointed out the following possibilities to increase the flexibility of existing conventional power plants:

* Especially older power plants can be operated closed to their technical limit by making use of modern IT equipment
* Reduction of the minimal load by making use of co-firing options

Both options result in different investment needs. Yet, most of the power plants in Germany have been analysed in this regard and retrofit measures have been carried out numerous times (BMWI & dena 2013).

Case study 1 – Flexibilisation of base load power plants

The flexibilisation of a North American Coal Generating Station (CGS) provides an overview of challenges and opportunities of the flexibilisation of base load power plants. The CGS that was reviewed in this case study was connected to the grid in 1970 and operated as a base load power plant running at 50% of its capacity. Since the 1980s the power plant`s steam generator and supporting equipment were modified to adapt to a more flexible generation. Necessary investments in hardware adaptations were undertaken and cost around 9,1-11,4 million €[[4]](#footnote-5) per unit (NREL & Intertek 2013)[[5]](#footnote-6).

The flexibility portfolio of the CGS comprises the following characteristics:

* Start up and shut down twice daily
* Load follow at minimum generation levels: from maximum capacity of 480 MW/unit to 90MW/unit
* Provide automatic generation control (recently retired)
* Increased efficiency and flexibility by operation at sliding pressure

Initially the flexibilisation of the CGS was introduced due to the introduction of a competitive market in the 1990s. Thus there can be other motives to increase power plants flexibility in addition to renewable integration.

Although the CGS power plant has increased its flexibility and therefore the number of start-ups over the course of its lifetime, it has to be noted that in comparison to other coal power plants the number displayed in Table 4‑1 are low. Parsons Brinckerhoff (2014) stated that flexibly operated coal power plants may have annual start up numbers of up to 200 and therefore exceeding start up number of the CGS plant.

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| Table 4‑1: Average number of starts at CGS over course of the plant lifetime |

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| --- | --- |
| Cold (7-8 hours to full load) | 523 |
| Warm (4 hours to full load) | 422 |
| Hot (1.5 hours to full load) | 814 |
| **Total** | 1,759 |

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| Source: Authors‘ own depiction based on (NREL & Intertek 2013) |

With the flexibilisation of the base load CGS and an increased cycling between high and low load areas, materials and infrastructure were under bigger stresses. Therefore life expectancies were reduced and higher outage rates followed. The CGS is planned to be shut down before the end of its life time.

Flexibility of conventional power plants is to a large extent dependent on their fuel type (see further below). But also within one fuel type, the flexibility can differ. Fraunhofer IWES (2015) pointed out that nuclear power plants in France have been operated in a flexible manner. This flexible generation can be provided especially by more modern reactors. Some reactors in France are able to reduce their power to 20 percent of their maximal output and operate one or two large power changes per day.

However, in other countries nuclear power plants are mainly operated in base load production. This shows that development in technologies as well as retro-fit measures can lead to an increase of flexibility within the conventional power plant fleet (EPRI 2010)**.**

Case study 2 – Nuclear power plants in flexible mode

Fraunhofer IWES (2015) studied the development of the residual load in France and flexibility requirements that thermal power plants need to meet based on scenarios formulated in the generation adequacy forecast of the French grid operator RTE. The basis for this analysis are a 30% and a 40% scenarios defined in the generation adequacy report (RTE 2014).

Fraunhofer IWES (2015) showed similarities between the load gradient requirements of thermal power plants in both scenarios to complement renewable generation: *“[…] aggregate patterns of the two scenarios do not differ significantly.”* Therefore the adjustment of thermal power plant operation will be necessary in the near future.

In France a large share of this generation is provided by nuclear power plants. Although nuclear power plants are operated as base load power plants due to economic reasons and reasons of operational simplicity, they also are able to adapt to load developments and can already be observed today. Figure 4‑6 below shows the generation of four nuclear generators in the second week of July in 2016. The figure shows the generation pattern of two older reactors (Fessenheim 1, Tricastin 4) which were installed in 77 and 81 and two younger reactors (Golfech 2, Saint Laurent 2) which were installed in 94 and 83.

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| Figure 4‑2: Generation of Fessenheim/Tricastin 4, Golfech 2, Saint Laurent 2 in the 2nd week of July 2016. |
|  |
| Source: Own depiciton based on (RTE 2017). |

It can be seen that younger reactors vary in their generation to a larger extent and thereby show a higher level of flexibility. In comparison to this the generation of the older reactors does not vary significantly. This illustrates that especially younger reactors can provide a certain amount of flexibility.

It has to be noted that start/stop operation stresses power plants through additional wear and tear (Rothwell & Rust 1995) and may even risk its safe operation (OECD & NEA 2012).

**Which power plants technologies are most suitable to ramp up and down?**

The development of conventional power plants has been driven by the system needs of base, middle and peak load on the one hand and regional availability of energy sources (like lignite) on the other hand. As a result conventional power plants differ regarding load gradients, minimum load and start up times.

The following

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| Table 4‑2: Load gradients, minimum load and start up times of power plants of different technologies |

Table 4‑2 summarises the main indicators for the degree of flexibility of power plants. It can be seen that especially coal fired plants as well as nuclear power plants are most suitable to deliver base load. Gas turbines on the other hand are much more flexible. However, gas plants show major differences within the range of technologies.

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| Table 4‑2: Load gradients, minimum load and start up times of power plants of different technologies |

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| --- | --- | --- | --- |
| Fuel and technology | Maximum change (during full load) | Minimum load | Start-up time from cold |
| Hard coal - steam | 2 - 8 %/min | 20 - 50% | 4 - 8 h |
| Lignite – steam | 2 - 8 %/min | 40 - 70% | 6 - 15 h |
| Nuclear – steam | 5 - 10 %/min | 50 - 60% | 12 - 25 h |
| Gas – steam | 6 - 12 %/min | ca. 40% | 2 - 5 h |
| Gas – turbine | 10 - 25 %/min | none | ca. 20 min |
| Gas – combined cycle | 4 - 10 %/min | 20 - 40% | 1 - 5 h |

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| Source: (DENA 2010; Eurelectric 2011; Genoese 2010; Grimm 2007; Klobasa et al. 2009; Matthias et al. 2009) indicate similar values. |

The power plant fleet does not only consist of fossil fuelled power plants but also of pumped hydro storage plants as well as hydro storage plants. Those plants do not face restrictions like minimum load or start up times.

Pumped hydro storage plants are classical storage plants which provide a maximum of flexibility. Hydro storage plants (major examples are plants in Norway or the Alps such as in Switzerland and Austria) also offer a great degree of flexibility in generation even though no pumping is possible. For a detailed analysis of the development of pumped hydro storage plants, please refer to “4.2 Storage capacity and development”.

Additionally dispatchable capacities can be provided by biomass and biogas power plants as they do not depend on intermittent energy sources. The flexibility of biogas plants is restricted by the gas generation profile and they can be flexibilised by gas storages. When it comes to load gradients biomass power plants can be compared to conventional technologies depending on the fuel type. Biogas power plants show similar characteristics as conventional gas power plants. Biomass power plants on the other hand are rather comparable to hard coal power plants.

Discussing flexibility, power plants that deliver heat as well as electricity (CHP-plants) have to be explained in more detail. CHP-technology has been implemented in order to increase the overall efficiency of power plants. However, long term contracts for delivering heat decreases the plants ability to generate electricity according to the system needs. In these cases electricity will be fed into the system even though RES-E power plants would be able to cover the electricity demand. As a result, electricity production from CHP-plants based on fossil fuels can stop RES-plants from producing. Having said this, the flexibility of CHP plants can relatively easy be increased by making use of heat storages to decouple heat and electricity generation. CHP plants with heat storages are able to follow RES-E genreration and supply heat demand. Hence, as long as the share of CHP plants with heat storage is low, a high share of CHP plants within the system can reduce overall flexibility. On the other hand one could argue that the potential for increasing flexibility is large if many CHP plants are available within the system that can be retro-fitted with heat storages.

**How did the shares of certain technologies within the European power plant fleet evolve throughout the last decade and, as a result, has the flexibility been increased?**

Countries with a power plant fleet that mainly consists of gas fired plants as well as a fair share of storage hydro power plants can be considered to be able to provide a high level of flexibility. On the other hand, countries with a high share of nuclear and coal fired power plants can be considered to be in need of flexibility as soon as RES-E shares reach significant levels. The following figure shows the development of the main types of generation for the whole of the EU-28 over the last decade.

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| Figure 4‑3: Installed capacity of main technologies of conventional power plants in operation from 2005 to 2015 within the EU member states |
|  |
| Source: Own compilation based on Platts 2015 data |

The data shows that especially the number of gas fuelled power plants has increased over the past ten years. This effect is also illustrated in the following Figure 4‑4. However, this figure also shows that coal fired plants are also on the rise again.

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| Figure 4‑4: Additionally installed capacity of main technologies of conventional power plants per year from 2005 to 2014 within the EU member states |
|  |
| Source: Own compilation based on Platts 2015 data |

As discussed before the share of CHP-plants does also affect the flexibility of the overall power plant fleet. Figure 4‑4 shows that CHP plants do have a significant share within the gas fired plants. If those CHP plants are fitted with heat storages the flexibility of the overall power plant fleet can be further increased.

Figure 4‑5 displays the planned capacities per year for the years from 2015 to 2020. Based on this data, the trend towards a higher share of gas power plants can be assumed to continue.

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| Figure 4‑5: Planned new capacity of main technologies of conventional power plants per year from 2015 to 2020 in EU Member States |
|  |
| Source: Own compilation based on Platts 2015 data |

Generally the data shows that planned capacity is mainly gas-fired and the EU power plant fleet thus tends to develop towards a higher share of gas fired plants.

In sum, most of the newly installed capacities as well as the planned plants are based on gas. Those plants can be rated to be quite flexible and therefore suitable to accompany a further increase in generation from variable RES-E.

**Conclusions:**

* Adaption of plant operation seems to be the first step towards a more flexible generation from the conventional power plant fleet. In Germany for example flexible generation from coal fired plants can be verified. This adaption can be carried out within the technical limits and also through retro-fit measures.

Power plant fleets with high shares of gas fired plants can be assumed to be more flexible due to high load gradients (see table

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| Table 4‑2: Load gradients, minimum load and start up times of power plants of different technologies |

* ). Therefore the ability to accompany variable RES-E generation is much higher.
* CHP plants have to follow the demand for heat in most cases and therefore cannot provide much flexibility for the electricity market. However, heat storages can decouple electricity generation from heat generation and therefore increase a plants flexibility. One could argue, that power plant fleets with high shares of CHP plants have a high potential for providing flexibility.
* The European power plant fleet has increased its share of gas fueled plants. In general, this points towards a more flexible power plant fleet.
* Overall it can be concluded that the need of flexibility in most MS has not increased drastically within the last decade and therefore only little changes have occurred within the conventional power plant fleet. Retrofit measures have made coal fired plants more flexible and therefore the need for a strong shift towards flexible gas power plants cannot be verified by the data analysed.

## Storage capacity and development

Storage plants as providers of positive and negative flexible capacity will play a major role in an electricity system with large quantities of variable generation from renewable sources. There are different types of storages that can be used to integrate renewable generation of which pumped hydro storage (PHS) is the most mature one. Other technologies such as battery storages or compressed air storages are not yet developed to a competitive level[[6]](#footnote-7). The storage capacity development can give an impression of the ability of a system to integrate renewable energy sources.

Pumped hydro storages are present in fourteen European Member States. Figure 4‑6 provides an overview of the development of PHS capacity in European Member States. The total installed capacity of 24 GW has hardly changed since 2005.

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| Figure 4‑6: Development of PHS capacity in EU-28 since 2005 |
|  |
| Source: Authors‘ own depiction based on (European Commission 2015b). Member States that are not included do not |

An analysis of European PHS potentials shows that there are still unused potentials, which could be exploited. (Gimeno-Gutiérrez & Lacal Arantegui 2013) analyzed the number of possible storage sites for different distances between storage reservoirs in Europe. They found 99 sites with a reservoir distance of up to 5 km, which would add up to 200 GWh of storage capacity. For greater distances even larger potentials were identified. The capacity of turbines and pumps can be varied independently of the reservoir capacity to fit the operator’s needs. With an exemplary capacity/storage capacity racio of 1/5, which can be observed for PHS in practice, an exploitation of the entire storage capacity potential could yield a capacity of 40 GW. It has to be noted that although PHS can already be operated economically today, new investments are often difficult, for economic and acceptance reasons.

Battery storage is a technology that increasingly becomes attractive especially when it can support self-consumption options. Currently battery storages are installed in Germany primarily in combination with small scale PV systems. Since 2013 numbers are increasing as can be seen in Figure 4‑7. This can be explained by the current support scheme for PV battery storages which was introduced in 2012 (Kreditanstalt für Wiederaufbau 2016) and provides investment support for PV battery storages through low interest rates and a financial support. According to (ISEA RWTH Aachen 2016) the total storage capacity adds up to approximately 60 MWh as of January 2016 as individual storages provide around 5.8 kWh of storage capacity.

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| Figure 4‑7: Number of installed PV-storages in Germany |
|  |
| Source: Taken from (ISEA RWTH Aachen 2016). English translation added by author. |

Figure 4‑8 shows the development of the total cumulated battery storage capacity in Europe since 2012. The figure is based on data from the Global Energy Storage Database (Sandia National Laboratories 2016) and includes data of storages with a charging capacity above 15 kW that are already realised or are planned to start operation in the future. As can be seen both the storage and the charging capacity have increased until 2017, thus providing an increasing amount of flexibility to the system. For projects with a total capacity of 86 MW information on the commissioning date was not provided. Therefore their capacities were added to the 2017 values as dotted lines if possible[[7]](#footnote-8).

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| Figure 4‑8: Cumulated battery storage capacity in European Member States since 2012 (including storages 15 kW and larger) \*) |
|  |
| Source: Authors‘ own depiction based on (Sandia National Laboratories 2016)  Capacity in 2017 is based on planned commissioning date. Dotted line indicates storage projects with no commissioning date, which could be realized in 2017. No claim to completeness.  \*) This includes the following Member States: Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Portugal, Spain, Sweden, United Kingdom. |

It can be concluded that the largest share of European storage capacity can be assigned to PHS with a total of close to 25 GW. Although the capacity of all electro chemical storages, which amounts to approximately 346 MW in 2017, is far lower. Its capacity has been increasing since 2012 and is expected to further increase with technological progress.

Case study 3 – Large scale battery storages

Next to battery storages with low capacities that are installed in combination with a solar panel on a household level also storages on a larger scale are already connected to the grid and operating. In practice these are subsumed with other technologies under the term “grid energy storages”.

Although these storages are not as common as other storage technologies the following two examples illustrate their practical application:

**Feldheim battery storage**

The Feldheim battery storage is located in Brandenburg, Germany which is an area characterized by high shares of wind generation. The battery storage provides 10 MW of capacity and 10 MWh of storage capacity in the reserve market (www.energiezukunft.eu 2015).

**Fukushima prefecture battery storage**

The Fukushima battery storage that is operated by Tohoku Electric Power Company is one of the largest battery storage technologies in the world. It provides 40 MW of capacity and 40 MWh of storage capacity (Toshiba 2016).

## Demand side flexibility capacity

The ability of consumers to adjust their consumption to the generation of renewable generation will be important to integrate renewable electricity into the system. Both large and small consumers can be more flexible in the future.

Larger consumers, which are primarily located in the industrial and trade sector, can already participate in certain European reserve markets and offer their flexibility. Small consumers, such as households, on the other hand can currently hardly participate in markets.

The most accurate indicator for the ability of a system to integrate fluctuating generation through demand side adaptation is the actual flexible demand capacity. It has to be noted that this type of capacity is constrained by other factors that do not apply to conventional flexible capacities from e.g. gas power plants. Flexible consumption is always constrained by consumption patterns and human behaviour. Moreover, demand side flexibility options are available for shorter periods or allow only short shifts of these periods in time.

Smart meters are the basis for the communication of prices and incentives from the market to consumers and therefore a step towards the flexibilisation of demand. The state and the policies of a European Member State smart meter roll-out can therefore point out the progress of the flexibilisation of demand.

Figure 4‑9 shows an overview of Member State discussions and decisions on a smart meter roll out from 2010 to 2013. In 2010 some countries did not report any activity in this area, meaning that there were no intentions to implement a smart meter roll out. These were Slovakia, Ungary, Romania, Bulgaria, Estonia and Lithuania. Nonetheless in 2013 Romania and Estonia decided towards a roll out among other states, which indicates that these were in the process of a discussion. Others reentered the political discussion on this topic, e.g. Slovakia, or decided against its realisation, e.g. the Czech Republic. Four Member States did not opt for a roll out, yet the majority of Member States did so.

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| Figure 4‑9: State of European Member States considering a smart meter roll out (information as of 2010) | |
| **2010** | **2013** |
|  |  |
| Source: Authors‘ own depiction based on (GEODE 2013; Giglioli et al. 2010); Red = No activity; Yellow = No decision yet; Green = Going ahead; Grey = N/A | |

The planned time period of roll out policies of different European Member States can be seen in Figure 4‑10. 16 Member States decided to implement a roll out, which are more than half of European Member States. Sweden and Italy already completed the roll out for at least 80 % of electricity consumers as stated in the European Commission staff working document (European Commission 2014a)[[8]](#footnote-9). Although Malta did not manage to complete its rollout in 2014, the majority of consumers were provided with a smart meter (Buttigieg 2015).

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| Figure 4‑10: Smart meter roll out policies in different European Member Stataes |
|  |
| Source: Authors‘ own depiction based on (European Commission 2014a) |

It is important to note that merely rolling out smart meters does not necessarily lead to significant increase in system flexibility. Research on flexibilized household consumption comes to rather conservative results as regards the actual flexibility. (Broberg & Persson 2016) conducted a survey among Swedish households to evaluate their preferences concerning external control of household heating and electricity. The results show that consumer highly value the absence of external control. Flexibility of households therefore could also be realized by the introduction of flexible tariffs and less by direct control. Nonetheless households tend to react poorly to changes in the electricity price (Labandeira et al. 2010). In Sweden households show only little interest in time-of-use tariffs. Only 0.2% of all Swedish households signed real time contracts, which need to be provided on demand by the electricity supplier (Swedish Energy Markets Inspectorate 2014). In some cases the introduction of time-of-use tariffs can even lead to counter intuitive consumption patterns not oriented by time-of-use prices, as found by by (Torriti 2012) in an Italian study. Additional consumption peaks emerged during the day after time-of-use tariffs were introduced failing to address peak consumption issues.

When interpreting the development of smart meter roll outs in Europe these effects should be taken into account. An increase in system flexibility may follow from this, but the overall effects may also be relatively small.

Demand side flexibility may also be provided through the flexibilisation of a number of industrial processes. Especially viable are processes that can shift consumption in time (Hartkopf et al. 2012). In practice these are especially processes that can store a final or intermediate product to interrupt or increase the process and thereby consumption of electricity. Examples include:

* Aluminium production
* Chlorine production
* Paper production
* Steel production through an electrical process
* Waste water treatment
* Cement production

An integration of small and large consumers into electricity markets can increase the flexibility provided to the system. In European Member States different states of consumer integration to electricity markets can be observed.

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| Figure 4‑11: Development of the introduction of demand side flexibility to electricity markets in Europe from 2013 to 2017 | |
| **2013** | **2014** |
|  |  |
| **2015** | **2017** |
|  |  |
| Source: Authors‘ own depiction based on (SEDC 2014, 2015, 2017); Blue = No information; Red = Closed; Orange = Preliminary developed; Yellow = Partial opening; Green = Commercialy active; Dark green = Commercialy active, standarised arrangements between BRP and aggregator in place | |

Figure 4‑1 shows the state of the introduction of demand side flexibility into electricity markets. It can be seen, that depending on the Member State the possibilities to participate differ strongly. Markets in Member States such as Spain or Italy are closed for the participation of flexible demand. Other Member States such as Germany or Poland are on the way towards participation. Commercial activity can be observed in a few states such as France and Switzerland. Currently especially the participation of large consumers or participation via pooling to reach minimum bid sizes can be observed in European balancing markets.

Case study 4 – Participation of large scale electricity consumption in reserve markets

UBA (2015) assessed the potential of flexible industrial electricity consumption to integrate renewable energies into the electricity system and to provide reserve capacity in the scope of the “Verordnung über Vereinbarung zu abschaltbaren Lasten” (Deutscher Bundestag 2016). Different projects were evaluated in this research.

In Great Britain the participation of electricity consumers that provide capacities of 50 MW or more in the reserve market is possible. 2,500 MW of capacity is contracted each month that can provide fleixble capacity in two minutes or faster. Similar projects can be found in Italy and Spain.

In the US flexible consumption can also participate in the capacity market to secure sufficient consumption in the electricity system. The program which is called “Reliability-Pricing-Model” (see e.g. (PJM 2012)) provides different participatory conditions for electricity consumers. These are the following:

* Direct-Load-Control – Typically heating and cooling appliances are directly controlled by the control area authority
* Firm-Service-Level – Consumers agree to reduce their conusmption to a minimum after being contacted by the control area authority
* Guaranteed-Load-Drop – After being contacted by the control area authority the consumer sheds an agreed amount of consumption or activates own electricity generation appliances

Overall, it can be said that the European Member States are implementing different forms of demand side flexibility. In the case of Smart Meter different roll out policies have been formulated and in some cases already realized. Also, for large-scale flexibility options in some Member States these policies are not developed in other countries the commercial participation is already possible.

## RES-E network integration and smart grids

The development of smart grids is used as a proxy for network integration of RES-E, as Smart Grids are observable, controllable, automated and fully integrated distribution grids that consist of different generation, consumption and flexibility units (Department of Energy and Climate Change 2009). Next to reliability, power quality and security benefits also economic and environmental benefits are associated with the application of smart grids (EPRI 2010). Although the implementation of this progressive solution seems attractive, in principle it is still possible to solve the problem it addresses merely by grid expansion. This could solve scarcity and congestion problems by allowing unconstraint transportation of electricity.

Currently it is not clear what the net effect of these grids is, so that a practical implementation was mostly realized in the scope of pilot projects to further study their impact. Figure 4‑12 shows the development of smart grid projects since 2001. The majority of these projects are demonstration or research projects. Deployment projects were rarely realized (JRC 2011).

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| Figure 4‑12: Smart grid project deployment in Europe from 2001 to 2011 |
|  |
| Source: Taken from (JRC 2011) |

(JRC 2011) named 165 projects, which were present in 2011. In contrast to this in 2014 a total of 459 projects were realized. Of these projects 211 were research projects and 248 deployment and demonstration projects (JRC 2014). As of September 2016 the database accompanying the survey for the collection of European smart grid projects (JRC 2016) contained 503 projects. This indicates an increase in total number of projects in Europe over the course of the years.

In parallel different smart grid initiatives were founded in Europe to further support the development of smart grids through cooperation and networking (SmartGrids 2016). These network formulated a roadmap that describes the necessary research areas and challenges until 2035 (SmartGrids 2012).

## Electricity market design

In addition to the technical infrastructure that acts as a basis for the integration of renewable energy also European electricity markets and certain design features can support their integration. The ability of a market to help integrate renewables can be evaluated by its volume and liquidity as well as the time delay between electricity trading and delivery. If markets are not designed optimally, flexibility cannot be used efficiently. This can ultimately increase flexibility demand.

### Intraday market volume and liquidity

The variability of renewable generation leads to difficulties in the delivery of electricity. Typically the real time generation deviates from the predicted generation due to forecasting uncertainties. A liquid intraday market can provide supply of or demand for electricity in times of unexpected deviations from planned generation.

The market volume of European intraday markets describes the amount of electricity that is traded in European trading areas. The larger the volume the greater is the exchange in a specific area and therefore the liquidity of this market. A very liquid market can trade electricity effectively and is a sign of high flexibility.

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| Figure 4‑13: Market volume of three different European intraday marekts since 2005 |
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| Source: Authors‘ own depiction; (EEX 2016; EPEX SPOT 2011, 2012, 2013, 2014, 2015a; Nord Pool 2006, 2007, 2008, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016a; OMIE 2012, 2013, 2014, 2015, 2016) |

Figure 4‑13 shows the different market volumes of European intraday markets. These markets cover the majority of Member States. EPEX SPOT operates markets in nearly each central European country. Nord Pool operates in the Nordic countries and OMIE is the operator of the Iberian electricity market.

In contrast to EPEX SPOT and Nord Pool, where market volumes have increased, the OMIE market exhibits a reduction in market volume. This has two main reasons: On the one hand the Spanish total electricity generation in 2013 was lower compared to other years and on the other hand the interconnection capacity with France steadily increased, which reduced barriers for trading on the EPEX SPOT market (European Commission 2014b, 2015c). The market volume in 2015 was larger than in all preceding years. Therefore it can be concluded that the flexibility that European intraday markets provide increased.

### Gate closure times and product resolution

Other indicators for the flexibility of the European electricity markets are the gate closure times of European intraday markets. With shorter gate closure times the forecast accuracy of RES-E increases, which in turn reduces unexpected deviations of renewable generation in real time. Increased forecast accuracy leads to an adjustment of generation and traded volumes prior to electricity delivery. Table 4‑3 provides an overview over adjustments of gate closure times that were realized in European intraday markets.

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| Table 4‑3: Gate closure times of different European intraday markets |

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| --- | --- | --- | --- |
| Market | Countries | Gate closure before delivery | Notes |
| EEX | Germany, France, Austria | 30 Minutes | Was between 45 and 75 minutes before 2015 |
|  | Switzerland & between all EEX countries | 60 minutes | Was between 45 and 75 minutes before 2015 |
| Nordpool | Norway Netherlands | 60 minutes | Was 120 minutes before 11 Nov. 2015 |

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| Source: (EPEX SPOT, European Commodity Clearing 2015; NordPool 2016b) |

Markets with lower gate closure times reduce the necessity for real time adjustments and the need for dispatching flexibility post market closure. Hence markets with short gate closure times can react more flexibly to deviations of generation.

In addition to the reduction of gate closure times the structure of products can provide flexibility itself. As generation of renewables may change quickly the division of products into smaller sub hourly products creates the possibility to adjust conventional generation to renewable ramps more accurately and thereby reduce the need for reserve capacity (Ocker & Ehrhart 2016). For example, 15 minute contracts were introduced in 2014 in the German as well as 2015 in the Austrian intraday market (EEX 2013; EPEX SPOT 2015b).

This is also true for balancing markets as smaller bid durations can provide access for a larger number of flexibility options. (ENTSO-E 2015c) conducted a survey, which showed that throughout Europe different timely resolutions can be found varying between hours, days, weeks, months and years. Long durations tend to exclude certain flexibility options that can provide flexibility only for a short duration.

These resolution principles can also be applied to the size of capacity products of balancing markets. Flexibility options that can provide only small capacities are excluded from markets with large capacity products. The same survey conducted by (ENTSO-E 2015c) in 2015 showed that not all European balancing markets have a high product resolution in terms of capacity. Dutch, Austrian and Czech balancing markets had a minimum bid size of at least 1 MW and thereby excluding smaller bids. The majority of Member States had minimum bid sizes of 1 MW or lower. Although this way a larger amount of individual flexibility options can be included in the market the coordinative effort connected to the coordination of a large number of small flexibilities is larger. A solution to this problem can be the introduction of pooling of small flexibility options to provide a larger capacity to bid in a balancing market.

### European grid and market integration

The integration of national electricity girds and markets provides additional flexibility in the European electricity system as has been pointed out by the European Commission (European Commission 2014c). The generation and consumption of electricity is not constrained to the national electricity system and may be transported to consumption centers in other Member States. Different consumption and generation profiles in different geographical regions can at least partly balance out each other and thus reduce the overall demand for flexibility.

#### Interconnection and electricity exchange between European Member States

The electricity grid and the ability to transport electricity between areas is a flexibility that is already important with low shares of variable renewable generation. An indicator for an increasing amount of RES-E integration is the development of electricity exchanges between Member States. With increasing exchanges a larger amount of electricity is transferred between states and transported from a generation to a consumption point. The need for temporal flexibility options such as storage is thus avoided.

Figure 4‑14 shows the development of overall cross-border electricity exchanges in the ENTSO-E area since 2009. The figure shows that with a nearly constant level of external exchanges with non-ENTSO-E states the internal exchanges were increasing. Additionally this figure shows the increasing amount of international electricity trades and ongoing market integration.

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| Figure 4‑14: Development of overall cross-border electricity exchanges in the ENTSO-E area since 2009 |
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| Source: Authors‘ own depiction based on (ENTSO-E 2010, 2015b, 2016) |

Grid expansion currently represents the most cost efficient way of RES-E integration, compared to flexibility options such as storages (Consentec & Fraunhofer IWES 2013).

The capacity of interconnections between Member States has been defined on a European level by the European Commission. Currently Member States are obliged to increase their interconnection capacity to 10% of the national generation capacity by 2020 and 15% by 2030 (European Commission 2015a).

#### Market integration

Optimizing electricity generation and especially renewable generation over larger areas provides for a better balancing of load and generation peaks and troughs. The network integration described in the previous section is a prerequisite, but what is also required is an integration of markets. The evaluation of electricity price convergence in different markets yields information on market integration and thereby optimization over larger areas.

The European Commission’s Single Market Strategy (European Commission 2016) aims to offer lower prices to consumers among others and aims to integrate European Markets. (Bosco et al. 2010) found a strong integration between the German, French, Austrian, Dutch, Spanish and Nordic markets (Bosco et al. 2010). These conclusions were drawn on the basis of econometric modelling and on time series data of electricity price developments in European markets from 1999 to 2006. (Nitsche et al. 2010) found pairwise integration between Germany, Austria, France and the Netherlands by applying econometric modelling to time series data of European electricity markets from 2004 to 2009. The proximity of these countries may be one of the reasons that market integration was realized. (Pellini 2014) conducted a literature review. She finds that there has been an integration of markets in the past especially in central continental European countries. Peripheral markets such as Spain and Norway on the other hand did not show a complete integration in the past.

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1. http://www.ewi.uni-koeln.de/fileadmin/user\_upload/Publikationen/Working\_Paper/EWI\_WP\_11-10\_Methodology\_to\_estimate\_security\_of\_supply-1.pdf [↑](#footnote-ref-2)
2. The residual load depicts the difference between load and variable generation over time. It is therefore often used to describe the necessary additional capacity and the amount of flexibility that is needed. [↑](#footnote-ref-3)
3. Overall it has to be pointed out that there is a lack of data concerning the operation of conventional power plants on plant level. Since 2015 the German EEX stock market publishes hourly data for each power plant. However, historical data is not available. [↑](#footnote-ref-4)
4. In 2013 € values. [↑](#footnote-ref-5)
5. Depending on the technology investment costs of coal power plants vary between 1.621 €/kW and 2.342 €/kW in 2015. Resulting in investment cost of 778 million € to 1,124 million € per unit. Based on (IEA 2016) and average exchange rates for 2015. [↑](#footnote-ref-6)
6. The installed capacity of compressed air storages is a constant 290 MW since the year 2005 (Platts 2015). [↑](#footnote-ref-7)
7. It was not possible to calculate the storage capacity for some projects, which was not added to the capacity shown for 2017. Therefore the 2017 capacity values might be larger in practice. [↑](#footnote-ref-8)
8. A roll out is only mandatory for states that found a positive impact on long term cost and benefits for market and individual consumers. For a detailed description see (European Commission 2014a). [↑](#footnote-ref-9)